

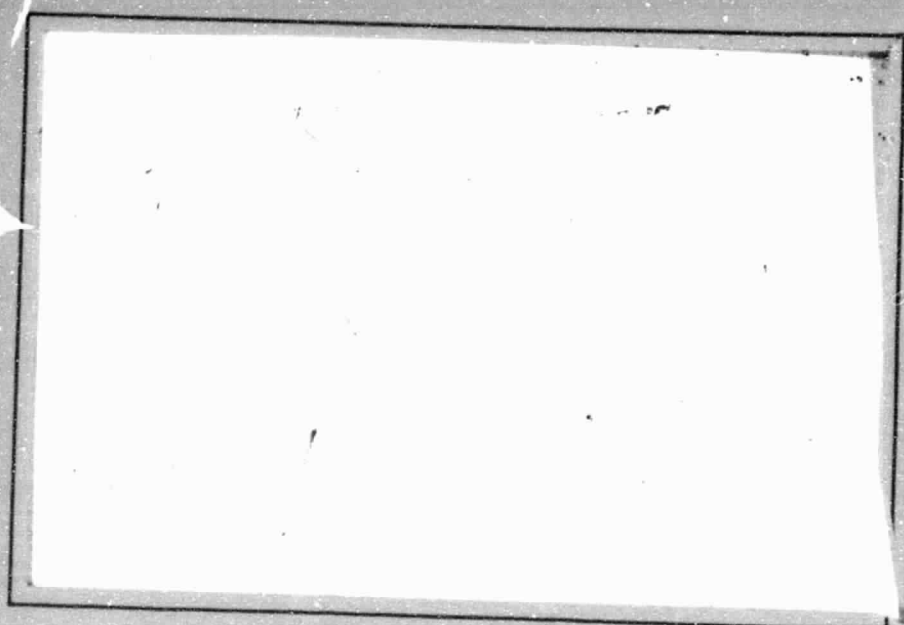
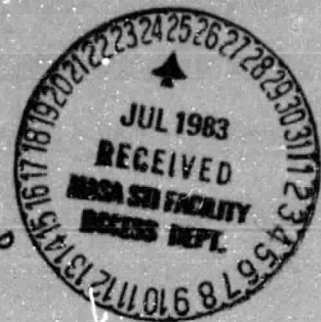
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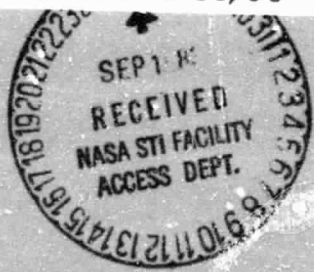


(NASA-CR-173063) A FUNDAMENTAL APPROACH TO
THE STICKING OF INSECT RESIDUES TO AIRCRAFT
WINGS Semiannual Technical Report (Virginia
Polytechnic Inst. and State Univ.) 17 p
HC A02/MF A01

N83-33875

CSCL 01C G3/05

Unclas
15134



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SEMI-ANNUAL TECHNICAL REPORT
A FUNDAMENTAL APPROACH TO THE STICKING
OF INSECT RESIDUES TO AIRCRAFT WINGS

by

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Prepared for
National Aeronautics and Space Administration

July, 1983

Grant NAG 1-300

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Literature Review

This literature search and review was conducted to accumulate information which is, or may prove to be, pertinent to the solution of the problem of the sticking of insect residues to aircraft wings. The major topics of this review are: experimentally tested methods, testing techniques, the effect of surface roughness height on aerodynamic drag, materials tested and, the adhesive properties of insect body fluids.

Experimentally Tested Methods

Many methods of eliminating insect contamination of aircraft wings have been attempted. These include: "superslick" films, hydrophobic coatings, sublimation coatings, mechanical scrapers, deflectors, fly-away covers, washing systems, and liquid films (6). The category of "superslick" films is of most importance to our project. One reference (11), in which five different surfaces and a liquid spray washing system were tested, reported that none of the surfaces showed any significant advantages in eliminating the insect contamination problems.

On the other hand, they found that the use of a continuous water spray while encountering the insects, during takeoff and climbout, is very effective in preventing insect contamination. Since most laminar flow aircraft employ a suction system to hold the boundary layer close to the wing surface, a spray system could be detrimental to the laminar flow control system. Not only would the spray nozzles have to be designed such that they would not cause transition of the flow when not in use (11), it was found that the residual liquid from the spray system

partially blocked the suction slots and tubing. Thus, we have some greater incentive for further investigation into "superslick" films.

Dr. F. X. Wortman suggested a resilient leading edge covering with which the insects would strike the surface and bounce away instead of sticking (4). When a light foam rubber was used as the covering there appeared to be a problem with rain erosion. The foam rubber could possibly be coated on its outer surface to improve erosion resistance.

Testing Techniques

B. H. Carmichael (4) suggested some different testing schemes with respect to insect contamination of aircraft wings. Initial sorting of test surfaces could be done in still air by expelling insects at high velocity from an air gun. Impact velocity could be controlled by a combination of chamber pressure and distance from the muzzle to the test specimen and measured by a rapid-acting gage monitoring the stagnation pressure at the specimen.

More realistic tests could be conducted in a wind tunnel provided that an addition screen downstream of the airfoil or test fixture was used to prevent contamination of the fine turbulence reduction screens located further down the wind tunnel. With either of these methods, it will be necessary to obtain a supply of insects; fruit flies seem to be the most readily available.

Carmichael felt that the use of automobiles is perhaps not advisable due to the low impact velocities inherent in such testing. He suggested the above testing schemes for a resilient leading edge covering for which high velocities were necessary for realistic

testing. However, the use of automobiles may be satisfactory for our investigation because the test would sample a realistic insect population. The most realistic test method would be to use an aircraft with a speed potential and lift coefficient similar to the climb speed of a modern commuter aircraft.

The Effect of Surface Roughness Height on Aerodynamic Drag

In our investigation, we are concerned with the amount and height of insect residue that remains on the aircraft wing which will cause transition of the flow. D. J. Marsden (10) attempted to assess the effect of insect contamination on the leading edge by using an artificial "bug pattern" as suggested by Richard Johnson. The bug pattern consisted of 3/16 inch diameter circles of tape 0.015 inch (0.038 cm) thick. These were placed on the leading edge at 6 inch intervals and on the upper and lower surfaces 1/2 inch behind the leading edge also at 6 inch intervals but falling between the leading edge "bugs". With this artificial "bug pattern" he found a 10-25% increase in drag coefficient over that for a clean wing over a range of lift coefficients.

Tests were conducted at Dryden Flight Research Center with a Jetstar airplane equipped with pitot probes to detect transition of the flow over the wings (11). It was found that after low flights over agricultural fields that insect residues ranging from 0.01 to 0.04 cm in height had collected on the wing leading edges. It was also found that insect residues in the bottom of the height range caused transition of the flow. To reinforce this result, they found from referenced curves that roughness heights above 0.008 cm could cause transition depending

on the shape of the particle. Another author (10) suggested that, for future laminar flow control aircraft, the allowable height of a roughness particle is between 0.010 and 0.015 cm before it will induce boundary layer transition.

R. F. Sturgeon (12) conducted wind tunnel tests of a subscale leading edge model to evaluate the effectiveness of a fluid film in preventing insect accretion. In his testing, he found that, when the airfoil was tested at 15° angle of attack, insect accretion extended back to 35% chord on the lower surface and as far as 5% chord on the upper surface. Therefore, any coating that is found to be effective in alleviating the insect contamination problem should be extended well back of the leading edge.

As far as wing surface waviness is concerned, one reference (3) found that the allowable ratio of wave height to wavelength is between 1/400 and 1/70 for transition to occur. Expressed in other terms, the allowable wave height is proportional to $(\text{wavelength})^{1/2}$ and $(\text{Reynolds number})^{-3/4}$. Thus, wing surface roughness, either in the form of roughness height due to insect contamination or as surface waviness, is a prime consideration in laminar flow control.

Materials tested

In an early test in England in 1952 (7), a section of the wing of a King Cobra aircraft was sanded smooth and coated with cellulose and again sanded as smooth as possible. (They were evidently aware of the importance of a smooth surface in laminar flow control.) They found that this surface was not completely effective in eliminating insect

contamination, but cleaning of the wing after flight was easier than with an uncoated wing.

Dr. F. X. Wortman suggested the use of a resilient leading edge covering with which the insects would strike the surface and bounce away instead of sticking. The most effective coating was found to be a silicone foam rubber with a high air content. There was a problem with rain erosion when this covering was tested, but its erosion resistance could possibly be improved by coating the outer surface with a protective film.

In 1978, five surfaces were tested on the wing of a Jetstar aircraft for their effectiveness in eliminating the insect contamination problem (11). The first two surfaces were superslick Teflon surfaces: Teflon pressure sensitive tape and a spray-on Teflon coating. The next two surfaces were hydrophobic coatings used in repelling water from aircraft windshields and radomes: organo-silicone hydrophobic coating and radome rain repellant coating. The fifth surface was a standard reference surface of polished aluminum alloy. Neither of the surfaces tested show any significant advantages in shedding insect residue, but the Teflon surfaces were easier to clean after flight than either of the hydrophobic or aluminum surfaces.

Adhesive Properties of Insect Body Fluids

Three references (1, 8, 9) were reviewed which dealt with the biochemistry of insect cuticle and insect hydrocarbons. None of these references were helpful in obtaining information on the adhesive properties of insects. Possibly more investigation should be made into the properties of insect waxes and their role in adhesion.

II. Preparation of Substrates

Two materials will be used as substrates for the polymeric films, 2024-T4 aluminum alloy and 410 stainless steel. The aluminum alloy was chosen as one which typically is used as the skin of an aircraft airfoil. Sand or glass-bend blasting will be used to create difference surface textures on the aluminum substrate prior to coating. Since the blasting process is to be performed by a hand held nozzle it is anticipated that some difficulty may be encountered in producing several samples with surfaces which are not statistically different.

The 410 stainless steel was chosen because of its magnetic and corrosion resistant properties. Because of its magnetic property, this stainless steel can be finished on a surface grinder. Samples which have been surface ground can be produced with no statistical difference in surface roughness. Three levels of surface roughness of the substrates will be used 0.2, 0.6, and 1.0 μm arithmetic average roughness.

The roughness of the coated substrates will be a function of the substrate roughness and the coating thickness. Stainless steel substrates with a roughness of 0.6 μm have been ground and these will be coated with polysulfone to determine the effect of coating thickness on the resulting roughness. While our primary method for measuring roughness is with a contacting stylus instrument, other techniques will be used for soft polymer films such as the depth of focus optical techniques and the SEM for qualitative assessment of roughness. Stainless steel substrates with roughness of 0.2 and 1.0 μm are currently being prepared.

III. Surface Energy

Sample Preparation

Solid polymer samples were obtained from Union Carbide. Three percent (w/v) solutions of polymer were prepared using chloroform and toluene for polysulfone and polystyrene, respectively. Solutions were cast to a 5 or 10 mil thickness onto either smooth glass or ferrotype plates using a doctor's knife. Solvent was allowed to evaporate by air drying for at least two days or drying under vacuum for at least 8 hours. Samples were kept in sealed containers until use.

Contact Angles

Contact angles (θ) were measured using either a series of different liquids of varying surface tensions (Zisman series) or a series of ethanol/water dilutions. The surface tension (γ) of the liquids in the ethanol/water series were determined by the capillary rise method as described by Daniels et al.(13). Droplets of approximately 5-6 mm in diameter were placed upon the substrate surface, and the contact angle measured using a Rame Hart contact angle goniometer (Model 100-00). Upon introduction of each droplet, the sample area was covered with a glass chamber to retard evaporation, and the contact angle measured within 30 seconds. Approximately 5-10 replications were done for each sample and both left and right contact angles were measured for each drop. The values for surface tensions and contact angles are listed in Table I.

Critical surface tensions for each polymer were determined by extrapolation of the $\cos \theta$ vs γ plots shown in Figures 1-3. The best line through the data points was determined by linear regression. The values for the critical surface tension are listed in Table II. The agreement for

polystyrene is good but the higher literature value for polysulfone may result from incomplete removal of solvent.

IV. Future Work

- Metal surfaces of defined roughness will be coated with different thicknesses of polymer films and the roughness re-determined.

- Critical surface tensions of six other polymer films will be measured.

- The tilting plate method will be used to assess the feasibility of determining surface roughness from differences in the advancing and receding contact angles.

- Coated metal coupons will be mounted on automobiles and insect impacts analyzed for thickness variability and composition.

V. Personnel Supported

Barbara Hall -Undergraduate Research Assistant - ME (hourly April - May, 1983).

David Gilliam -Graduate Research Assistant - ME (June - December 1983).

Frances Webster - Laboratory Technician - Chem (hourly, February-June, 1983)

Mia Sciotti - Graduate Research Assistant - Chem (June-December 1983).

VI. References

1. Andersen, Svend Olav. "Biochemistry of Insect Cuticle," Annual Review of Entomology, Vol. 24, 1979, pg. 29-61.
2. Carmichael, B. H. and W. Pfenninger. "Surface Waviness Criteria for Swept and Unswept Laminar Suction Wings," Norair Report Number NOR-59-438, (BLC-123), August 1959.
3. Carmichael, B. H. and W. Pfenninger. "Surface Imperfection Experiments on a Swept Laminar Suction Wing," Norair Report Number NOR-59-454, (BLC-124), August 1959.
4. Carmichael, B. H., "Summary of Past Experience in Natural Laminar Flow and Experiment Program for Resilient Leading Edge," NASA CR-152276, Ames Research Center, NASA, May 1979.
5. Cotta, Rick. "Increasing Aircraft Efficiency Through Laminar Flow Control," Aviation Engineering and Maintenance, Vol. 4, Jan. 1980, pg. 12-15.
6. Gratzner, L. E. and D. George-Falvy. "Application of Laminar Flow Control Technology to Long-Range Transport Design," Boeing Commercial Aircraft Co., CTOL Transport Technology, 1978, pp. 409-447.
7. Gray, W. E. and H. Davies. "Note on the Maintenance of Laminar Flow Wings," Aeronautical Research Council, London: Her Majesty's Stationary Office, 1952.
8. Howard, Ralph W. and Gary J. Blomquist. "Chemical Ecology and Biochemistry of Insect Hydrocarbons," Annual Review of Entomology, Vol. 27, 1982, pp. 149-72.
9. Lockey, Kenneth H. "Insect Cuticular Hydrocarbons," Comp. Biochem. Physiol., Pergamon Press Ltd., Vol. 65B, pp. 457-462.
10. Marsden, D. J. "Wind Tunnel Tests of a Slotted Flapped Wing Section," Canadian Aeronautics and Space Journal, Vol. 24, Mar.-Apr. 1978, pp. 83-91.
11. Peterson, John B. and David E. Fisher. "Flight Investigation of Insect Contamination and Its Alleviation," NASA Conference Publication 2036, Proc. of conference held at Langley Research Center, Hampton, VA., Feb. 28 - Mar. 3, 1978.
12. Sturgeon, R. F. "Evaluation of Laminar Flow Control Concepts for Subsonic Commercial Transport Aircraft," NASA CR-159254, Lockheed-Georgia Company, Marietta, Ga., Sept. 1980.

13. Daniels, F., J. H. Mathews and J. W. Williams, Experimental Physical Chemistry, McGraw-Hill, Inc., New York (1941).
14. Lloyd, D. R. et al., ACS Symp. Series # 153, A. P. Turbuk, Ed., 1981, pp. 327-350.
15. Ellison, A. M., H. W. Fox and W. A. Zisman, J. Phys. Chem., Vol. 57, 1953, p. 503.

TABLE I
CONTACT ANGLES OF LIQUIDS ON POLYMERS

Liquid	γ dynes/ cm	Polysulfone						Polystyrene	
		Glass Sub.		Ferr. Sub.		Glass Sub.		Ferr. Sub.	
		Air Dried 10 mil	Air Dried 5 mil	Vac Dried 10 mil	Vac Dried 10 mil	Vac Dried 10 mil	Vac Dried 5 mil	Vac Dried 5 mil	Vac Dried 5 mil
Water	72.8	81.8±1.1°	81.5±1.4°	80.8±0.7°	80.6±0.9°	80.6±0.3°	85.6±0.3°		
Formamide	58.3	61.3±1°	61.5°	63.0±1.1°	62.6±1.1°	-	-		
Methylene Iodide	50.8	20.4±0.9°	-	18.8±0.8°	19.2±0.8°	-	-		
Ethylene Glycol	48.3	53.7±0.7°	*53.6°	*48.5°	50.8±1.1°	-	-		
1-Bromo-Naphthalene	44.6	7.3±0.9°	-	6.3±1.1°	*5.9°	-	-		
Hexadecane	27.6	*1.5°	-	-	-	-	-		
<u>Water/Ethanol Series</u>									
10/90	55.4					76.0±3°	77.4±0.3°		
30/70	53.3					58.2±0.4°	57.5±0.3°		
50/50	45.1					45.9±0.3°	38.8±0.4°		
80/20	39.9					30.2±0.4°	16.9±0.3°		
90/10	38.0					15.6±0.4°	12.5±0.4°		

*Less than 4 replications

TABLE II

CRITICAL SURFACE TENSIONS OF POLYMERS

Polymer	Technique	γ_c (dynes/cm)	
		<u>This work</u>	<u>Literature</u>
polysulfone	Zisman	34.8	43.(14)
polysulfone	EtOH/H ₂ O	33.2	
polystyrene	EtOH/H ₂ O	36.5	33.(15)

Glass substrate, air dried
 Glass substrate, vac dried
 Ferrotype substrate, vac dr

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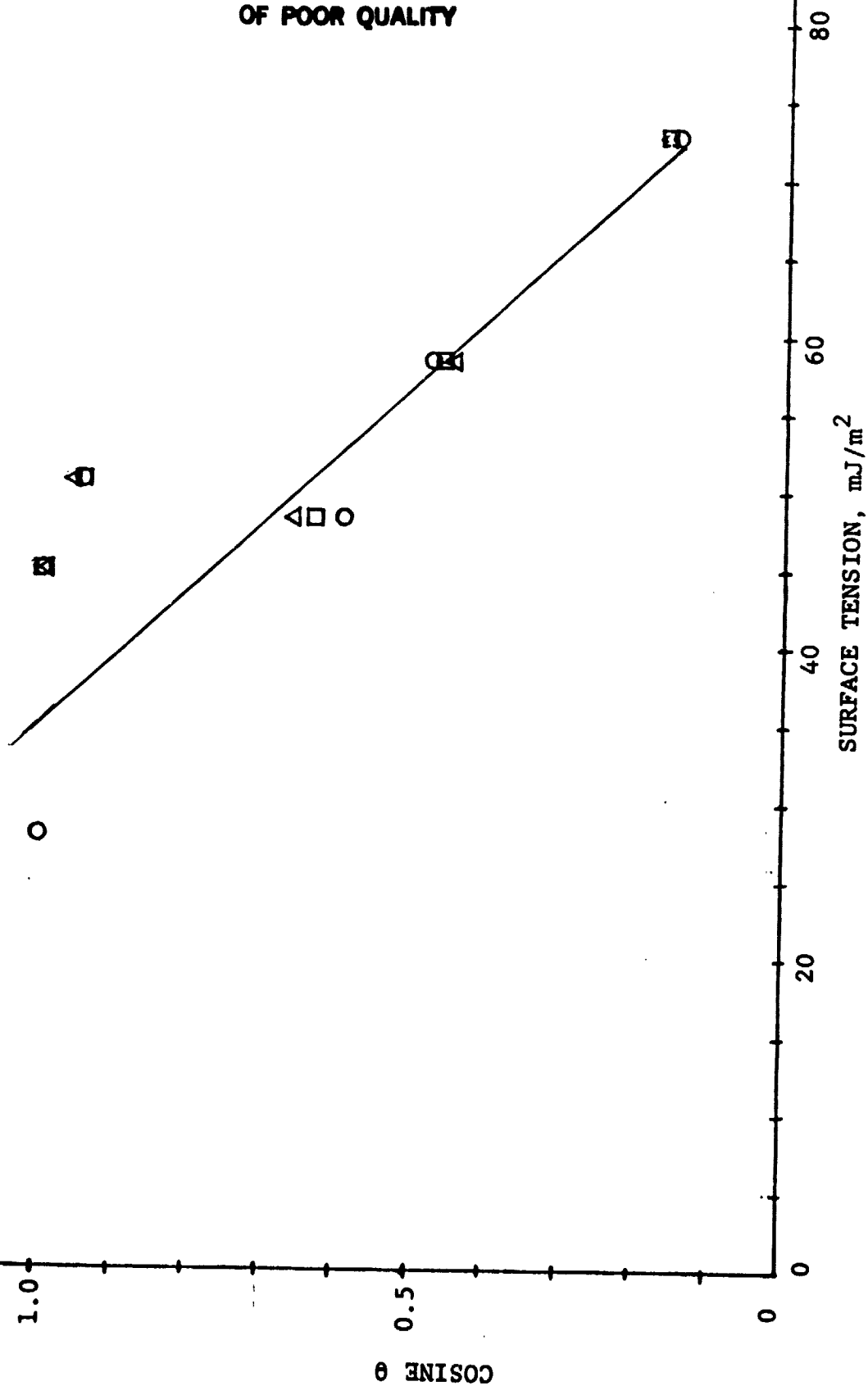


Figure 1. Wettability of polysulfone by Zisman series.

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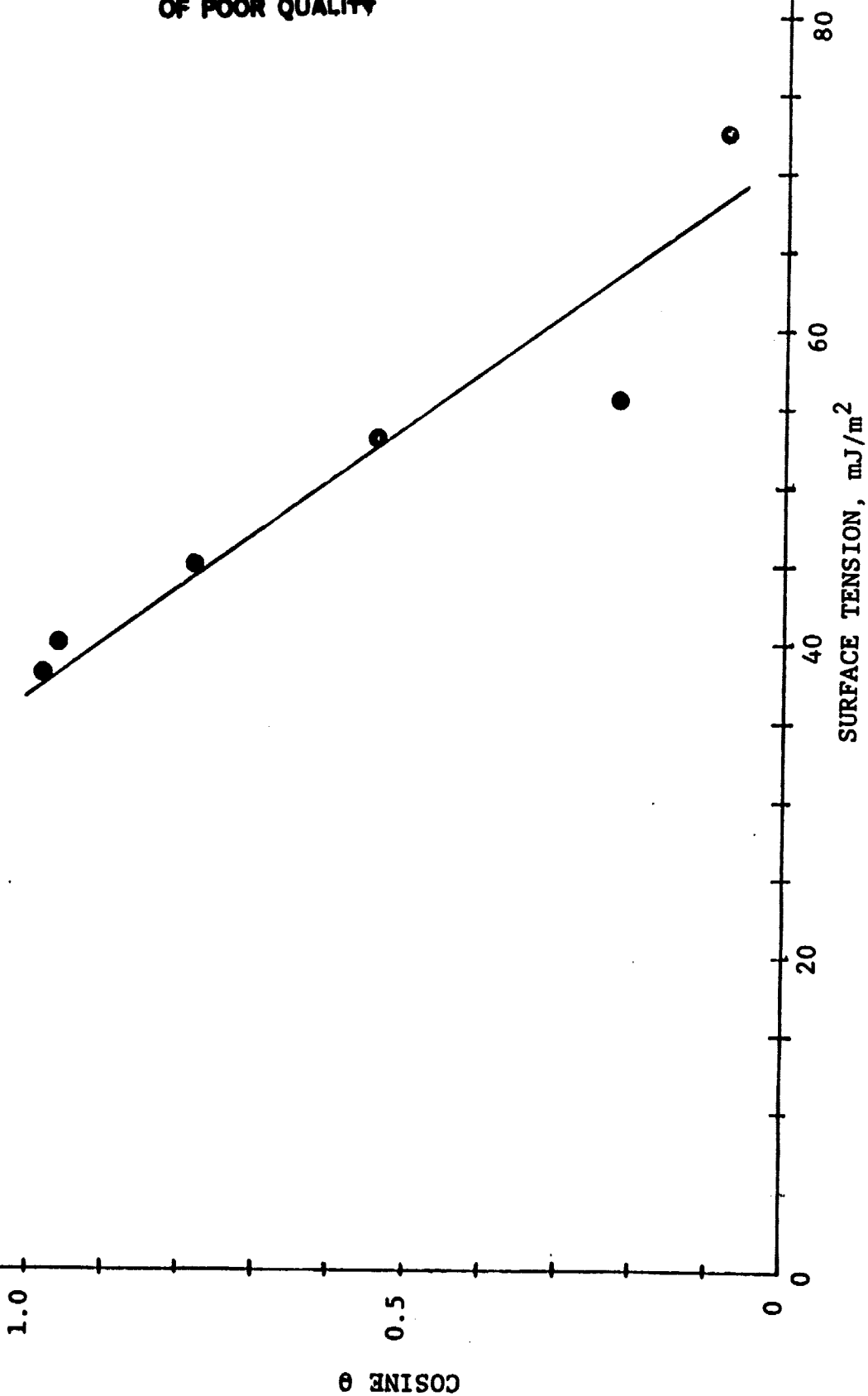


Figure 2. Wettability of polystyrene by ethanol/water mixtures.

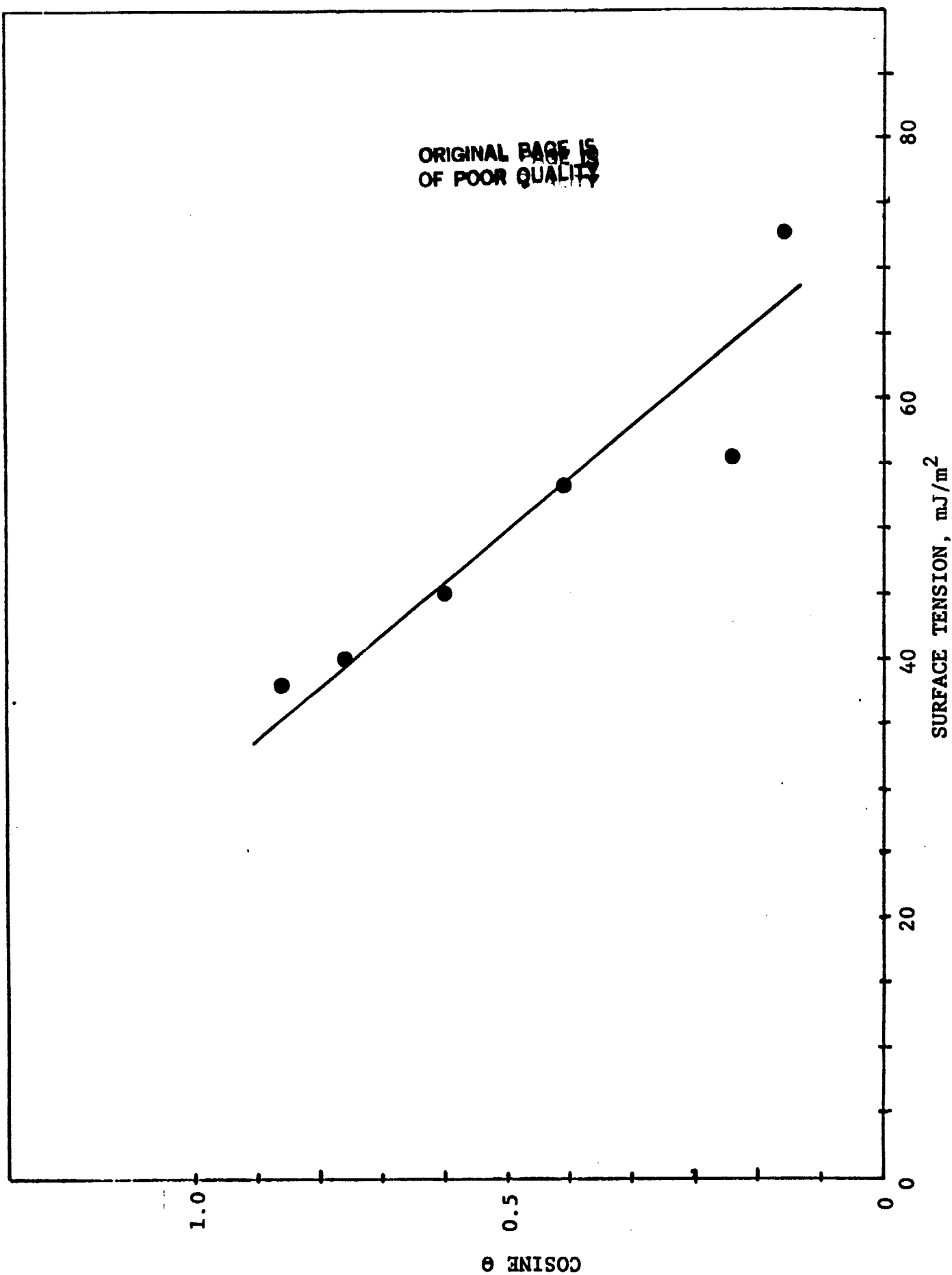


Figure 3. Wettability of polysulfone by ethanol/water mixtures.